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17

Battery Backup for the Life of the Product

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Session 17 Battery Backup For the Life of the Product

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BATTERY BACKUP FOR THE LIFE OF THE PRODUCT - AN OVERVIEW

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INTRODUCTION

As more computing power is being built into devices such as terminals, cash registers, data loggers, etc., more attention must be directed to how these devices will function during and after main power interruption. A desirable, and almost necessary feature is that such devices power up in a condition that allows them to continue their function without reinitialization by the operator. This means that devices like system time/date clocks should continue to run and that volatile data should be retained.

POSSIBLE NONBATTERY SOLUTIONS

There are many methods by which data retention might be accomplished. Core memories have been used, but they are large, require more power and are expensive. The same can be said for other conventional storage media such as hard disk and floppy disk. Bubble memories are an alternative but information retrieval is slow because access is sequential and expense is also a problem.

EAROM's and E^2PROM's are a popular alternative but even these have their drawbacks -- access times are measured in tens of milliseconds, the number of reliable writes is finite, and there is a sizeable software burden associated with storage of data after detection of incipient power failure and another to restore function after power up.

Shadow RAM's offer a method of avoiding some of the software burden by transferring with a single command the contents of a RAM to an E^2PROM contained in the same package. The burden of detecting incipient power failure still rests with the user.

BATTERY BACKUP AS A SOLUTION

Perhaps the most straightforward method of assuring data retention is to supply continuous power to the CMOS RAM chips which are already in use on the board. Continuous battery power is also the only way by which devices like clocks can continue to function during power down.

Several companies provide batteries for RAM backup applications and at least one provides a battery-RAM-switch module which senses impending power failure and provides a signal to the processor that the RAM will soon be on battery backup in a write-protected mode.

CHOOSING THE RIGHT BATTERY

Not all batteries are suited for CMOS RAM backup. Some are short lived, some leak, some have a questionable safety record. The ideal battery for CMOS RAM backup should exhibit these characteristics:

(1) Printed circuit board mountable
(2) Wave solderable
(3) Provide data retention for the life of the product
(4) Retain data over a wide temperature range
(5) Not require recharging
(6) Not require replacement
(7) Be hermetically sealed to prevent leakage
(8) Have a proven record of reliability
(9) Exhibit a high degree of safety

To this point, two generic battery types have been used as power backup systems: Nickel-cadmium rechargeables and several lithium systems. Rechargeables have several disadvantages: Somewhat narrow operating temperature range; replacement required after about four years of service; recharging electronics is required; leakage problems can occur; and backup time is limited to a few months in the absence of recharge. They are an excellent choice, however, when high currents or low cost are important factors.

LITHIUM BATTERIES

Lithium batteries in general can provide very long service life, ability to operate over a wide temperature range, and high energy density (watt-hours/cm^3), factors which are essential for backup and which conventional batteries do not provide. Almost all are hermetically sealed and some are PC board mountable using wave soldering techniques. However, lithium batteries bring with them their own set of concerns for designers:

(1) Some are limited in the maximum current they can provide
(2) Safety is a concern with some systems
(3) Some systems have not been available for more than a few years so long-term reliability may be questionable.

"Lithium battery " is a generic term. It is important that the designer recognize the differences among the lithium battery systems and choose the one best suited for his application. It is not wise, for example, to choose a lithium battery only on the basis that it has the highest capacity rating and fits in a particular slot on a PC board. That same cell, in a few years, may leak or lose much of its capacity to internal discharge processes.

TYPES OF LITHIUM BATTERIES

There are three basic types of lithium cells which have been offered for memory backup applications:

(1) Lithium-inorganic electrolyte
(2) Lithium-organic electrolyte
(3) Lithium-solid electrolyte

All provide a distinct advantage over conventional cells in terms of watt-hours per unit volume and all have the promise of long life.

Lithium-Inorganic Electrolyte Batteries

Only one version of this type cell has been seriously promoted for use in backup applications -- the lithium-thionyl chloride (Li-$SOCl_2$) cell. It is manufactured by Tadiran, GTE, Altus and others.

In addition to the lithium anode, the cell uses thionyl chloride ($SOCl_2$) the electrolyte solvent and a high-surface-area carbon as the cathode current collector. $SOCl_2$ serves not only as the electrolyte solvent but also as the active cathode species. Because one component serves two roles, the cell is very energetic (Ca. 1.1 watt-hours/cm^3). It functions well over a wide temperature range and has an attractive single cell voltage (>3.5 volts). It is capable of delivering moderate to high current (1-1000 ma) depending on cell design.

The system has also shown several disadvantages over the past few years. Self-discharge, the rate at which the cell consumes its own capacity internally, can be very high and unpredictable. Several manufacturers claim to have solved this problem, but multiyear testing is necessary to be certain.

Perhaps the biggest question with this system is safety. Very large batteries, designed for the military, have shown a few serious problems. Certainly the smaller versions of this cell with limited current capability are much safer. Moreover, several manufacturers claim to have solved the safety problems by mechanical means or by the use of additives. Nevertheless, some questions about this system still exist in the minds of battery professionals, and the electronics system designer would do well to be certain that for his application, all the safety requirements are met. Again, time and the testing of very large numbers of cells will tell the story.

Lithium-Organic Electrolyte Batteries

At least three types of lithium-organic electrolyte cells have been offered for memory backup:

(1) Lithium-manganese dioxide (Li-MnO_2)
(2) Lithium-carbon fluoride (Li-CF_x)
(3) Lithium-sulfur dioxide (Li-SO_2)

The Li-MnO_2 system is offered by Sanyo, Ray-O-Vac, Mallory and others. It is a moderate rate system (0.1-10ma)

with a voltage near 2.8 volts. In addition to the lithium anode, the cell uses a pellet containing MnO_2 as the cathode and an electrolyte composed of an inorganic salt dissolved in an organic solvent. Its energy density is moderate (Ca. 0.6 watt-hours/cm^3). It can operate over a fairly wide temperature range with low self-discharge. It has thus far shown itself to be a safe system and has promise to be a long-life (5+ years) system.

Its principal disadvantages are lower cell voltage, lower energy density, and lower rate than Li-$SOCl_2$. To many designers, these are outweighed by its advantages.

The Li-CF_x system is offered by Panasonic, Eagle-Picher and others. It is similar in most aspects to the Li-MnO_2 systems except for a slightly higher current capability.

The Li-SO_2 system is different from the other lithium-organic electrolyte in that it uses a soluble gas rather than a solid pellet as the cathode. It can build up pressure as it is discharged or heated and some of the larger cells use safety vents to prevent case rupture. A few safety-related incidents have been recorded with some of the larger cells, but certainly the smaller cells should cause little or no problem. Its energy density is about the same as other Li-organic systems and it operates over a rather wide temperature range. Its current capability is somewhat higher than Li-MnO_2 or Li-CF_x.

Lithium-Solid Electrolyte Batteries

Lithium-solid electrolyte systems are provided by Catalyst Research, Mallory and others. Unlike other lithium batteries, the electrolyte is solid, a distinct advantage for long life.

The solid electrolyte system which is most used is the lithium-iodine system. Its electrolyte is solid lithium iodide which accumulates as the cell is discharged. Unlike other cells, this cell uses no separator to prevent internal shorting of anode and cathode. The electrolyte itself is the separator, and should it form a crack, it "heals" itself. This is another important factor in the performance of this long-life system. The cathode is a pellet of iodine mixed with a small amount of organic to make it conductive.

This system is the cell of choice of the pacemaker industry, powering more than 90% of the worlds pacemakers. It boasts a real 10-year data base encompassing more than a million cells.

Its energy density is quite high (Ca. 0.9 watt-hours/cm^3) and its ability to deliver current is somewhat low (0.1 - 2 ma), but still high enough for data retention for many CMOS RAMS. Open circuit voltage is 2.8 volts.

There have been no safety-related incidents in its 10-year history.

INTERFACING BATTERY AND ELECTRONICS

Once the choice of battery has been made, the interfacing to the processor or other electronics may seem trivial. In fact, this is far from true. The designer must worry about the characteristics of the switch, logic level incompatibilities created by two power supplies, and drawing too much current from the battery during switch transitions. These and other topics will be covered in a later paper.

SUMMARY

Battery backup seems to be the ideal solution for data retention and powering devices like real-time clocks. When used with CMOS RAM's, battery back up offers the speed and cost advantages of RAM storage with the additional advantages of non-volatility.

Lithium batteries offer real advantages over conventional and rechargeable batteries, but care must be exercised to find the right lithium battery. Factors such as safety, energy density, and proven reliability must be considered.

With the proper choice of battery and interfacing electronics, it is possible today to design a system with a backup battery that can last the life of the product, a system in which the battery is treated like any other nonreplaceable component and soldered directly to the PC board.

LONG LIFE PRIMARY AND SECONDARY BATTERIES

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INTRODUCTION

Since the development of the electrochemical storage battery almost a century ago, a growing number of applications have employed batteries both as their only power source and as a back up supply during commercial power outages. In the last 100 years, a variety of battery chemistries have evolved both in primary and secondary batteries.

Today we are entering a microcomputer age where the demand for standby power to preserve volatile memories and to insure uninterrupted clock operation is increasing rapidly. Applications for standby power are in computers or process control equipment using real time clocks, computer printers where the customer initializes his printing format in volatile memories, portable data terminals used in inventory control, telecommunications, portable test equipment, and a growing list of other applications.

Miniature batteries are becoming an important tool to the microcomputer system designer. When complimented with power line sensing and write inhibit semiconductor devices, it enables the designer to use standard NMOS and CMOS RAMs without risking program or data loss. The designer can then continue using high speed low cost memories without sacrificing write speeds or having to resort to EPROMs or high priced low speed multi-voltage EEPROMs. Nor, is the number of write operations limited to some number X due to wear-out phenomena.

The purpose of the battery is to protect the microcomputer, its volatile memory, its clock circuitry, or any combination of these from AC line disturbances. To design a battery backup system, an engineer needs an understanding of power line disturbances. The types of abnormal power line conditions to be reckoned with are 1) Transients: a short term voltage or current disturbance having a duration between 1 nanosecond and 5 milliseconds. 2) Voltage Sags: a drop in voltage lasting more than 5 milliseconds but less than 5 seconds. The voltage value must be below the lower specification limit for nominal voltage. 3) Power Interruption: a complete loss of voltage for any period greater than 5 milliseconds, but less than 500 milliseconds. 4) Power Outage: a complete loss of voltage for any period exceeding 500 milliseconds. 5) Brownout: a deliberate reduction in nominal voltage supplied by the utility company. The value may fall at or below the lower limit specified for nominal voltage.

To quantify the problem, IBM did a study[1] of AC power sources for typical data processing equipment. The study involved 49 locations and 125,000 hours of monitoring. The study was made from July 1969 to July 1972. The information is broken down into duration of disturbance and percent of voltage lost.

During the 125,000 hours of monitoring 1,790 voltage sages, power interruptions, and power outages occurred; that is, one disturbance every 69 hours of operation.

Assuming the power supply can operate down to 80% of nominal line voltage, Figure 1 shows line disturbances that will cause memory problems. In 125,000 hours of operation there would be 1,040 disturbances, or one problem every 120 hours of operation. With the addition of a battery backup system, errors due to line disturbance can be controlled.

Additional considerations to be aware of are the electronic cash registers which may be shut off at night or on weekends and without battery backup could encounter loss of sales totals and/or inventory sold. Computerized office equipment involved in office moves and rearrangements can be subjected to power outages of several minutes, hours, or days. Without battery backup initialized data, accumulated data, and clock functions can be lost.

DURATION IN CYCLES	PERCENT OF LINE VOLTAGE SAG				
	20-60	60-70	70-80	80-90	TOTAL
.5 to 1	0	3	16	673	692
1 2	1	7	11	35	54
2 3	1	3	13	33	50
3 4	0	3	8	49	60
4 5	1	9	26	46	82
5 6	5	13	14	39	71
6 7	1	12	6	23	42
7 8	1	2	6	7	16
8 9	3	2	3	9	17
9 10	0	3	5	4	12
10 15	1	6	9	17	33
15 30	1	4	13	18	36
30 120	1	4	8	43	56
120 900	0	0	0	97	97
over 900	0	0	1	465	466
TOTALS	16	71	139	1588	1784

FIGURE 1 VOLTAGE SAGS FOR 125,000 HOURS

One additional problem is worth mentioning. Some computer products are manufactured and shipped with preprogrammed information. Batteries must be used for memory retention in the interim between shipment and installation by the end user.

The purpose of this paper is twofold: 1) to review the history of primary and secondary batteries used for memory backup applications; and 2) to present the most recent developments in lithium batteries as they relate to the microcomputer/microelectronics environment.

Before I get into the different battery systems, I'd like to establish some general characteristics of an "Ideal Power Cell" and use it as the yardstick to which all batteries are compared and measured. The "Ideal Power Cell" would have:

1. Maximum Energy Density - offer a maximum amount of energy stored in a minimum amount of space.

2. Unlimited Shelf Life - no self-discharge irregardless of storage period.

3. Rechargeable - fully rechargeable at any charging rate.

4. Light Weight - combine maximum energy density with a minimum amount of weight in the materials used.

5. Safe - the ideal cell would be completely safe - no leakage or gassing. The contents would be harmless to people and the environment.

6. Good Performance - deliver the required current and voltage under a wide range of temperature and load conditions.

7. Cost - the materials used to make the cell would be in plentiful supply, multisourced, and manufacturing costs would be minimal.

SECONDARY BATTERIES

Nickel-Cadmium Batteries

Nickel-cadmium rechargeable batteries are secondary batteries. They were first developed in the 1940's. Figure 2 is an overview of several battery systems and their respective energy densities. Although the nickel-cadmium battery has a low energy density, the fact that it can be recharged compensates for this characteristic.

Advantages of nickel-cadmium batteries are: they offer excellent rate capabilities, have a stable discharge voltage, perform very well at low temperatures (-20°C and below), and have an operational life of 3 to 5 years, or 500 to 1000 charges, whichever comes first.

Disadvantages are: it has a low energy density, an individual cell voltage of 1.2 volts requiring a stack of several cells to form a usable battery for memory backup/clock applications, a high self-discharge rate of 1% per day at room temperature and several percent per day at temperatures above 40°C, and if subjected to many shallow discharge/charge cycles can develop a "memory effect" where it can fail to deliver its full capacity when called upon to do so.

Figure 3 compares the nickel-cadmium to the ideal power cell.

Most applications employ batteries consisting of a 3 or more cell stack. Typical applications are for memory backup/clocks, calculators (LED), test equipment, toys, etc.

Sealed Lead Acid

Sealed lead acid rechargeable batteries are members of the secondary battery family. Conventional lead acid batteries with the liquid electrolyte have been available for over seventy years. Sealed lead acid batteries have been available for about 7 years. Figure 2 compares its energy density to

other battery systems. Although sealed lead acid batteries have a low energy density, the fact that they can be recharged compensates for this characteristic.

PRACTICAL ENERGY DENSITY FOR CELL SYSTEMS

ALKALINE SYSTEMS	MID-LIFE VOLTAGE V	ENERGY DENSITY WH/L	LITHIUM SYSTEMS	MID-LIFE VOLTAGE V	ENERGY DENSITY WH/L
AIR/ZN	1.3	970	$SOCL_2$/LI	3.5	760
AGO/ZN	1.55	650	AG_2CRO_4/LI	3.0	670
HGO/ZN	1.35	550	CF_x/LI	2.8	570
AG_2O/ZN	1.55	460	MNO_2/LI	2.9	520
MNO_2/ZN	1.3	230	SO_2/LI	2.8	450
CARBON/ZN	1.3	140	SOLID STATE	2.8-2.0	500-530
NICAD	1.2	75			
SEALED LEAD ACID	2.0	70			

CELL SIZE: 11.6 x 4.2 MM

DRAIN: 5 MICROAMPERES

FIGURE 2

Advantages of sealed lead acid batteries are: they have a nominal cell voltage of 2 volts, can deliver high currents, have a flat discharge, can operate over a temperature range of -40°C to +60°C, operational life of 3 to 5 years or 100 to 250 charges, and an ability to tolerate cell reversal without damage.

Disadvantages are: its low energy density, a self-discharge rate of 6% to 8% per month at room temperature, limited number of recharges, the smallest size available is comparable to a "D" size, and it is physically heavy.

Figure 3 compares the Sealed Lead Acid battery to the ideal power cell.

Sealed Lead Acid batteries are available in sizes from 2.5 AH to over 25 AH and in 2 volt increments from 2 volts to 48 volts. Typical uses are standby power for powering large blocks of memory at a 2 volt data retention level, uninterruptable power supplies for small to medium size computers, alarms, emergency lighting, and as cyclic power for tools, instruments, engine starting, televisions, and video tape recorders.

Mercury Batteries

Mercury primary batteries were first mass produced during World War II. Figure 2 shows mercury's energy density relative to other battery systems. As you can see, mercury is very high in the table and at the time of development was the highest energy density battery available. This characteristic also facilitated development of miniature button cell batteries having capacities in the hundreds of milliampere-hours.

Advantages of mercury batteries are their high energy density, flat discharge characteristic, good rate capability at currents from microamperes to hundreds of milliamperes, and an operating temperature range of -20°C to 60°C.

Disadvantages of the battery are: a cell voltage of 1.35 volts, a shelf life at room temperature of 1-2 years, problems of mercury migration during discharge which can internally short out the cell, the environmental concern of mercury disposal, and relatively high cost.

In some of the first computerized cash registers, 1 AH mercury batteries were used for memory backup. However, it was found that the batteries did not stand up well under the daily temperature cycling. Too often the cells would leak or go dead after one-half of their capacity had been expended. Coupled with the 1-2 year shelf life, the mercury battery bowed out of the memory backup market.

Figure 3 compares the mercury battery to the ideal power cell.

Present day applications for the mercury battery are in hearing aids, cameras, instruments, and smoke detectors, which benefit from its high energy density characteristics.

Alkaline Batteries

The alkaline manganese, or simply alkaline battery as it is commonly called, was developed about 25 years ago. While most of the alkaline batteries available today are primary

COMPARISON TO IDEAL POWER CELL

CHARACTERISTICS

CHARACTERISTIC	IDEAL POWER CELL	SEALED LEAD ACID	NICAD	MERCURY	ALKALINE	SILVER	LITHIUM
MAX ENERGY DENSITY	High	Low	Low	High	Med	High	High
SHELF LIFE	Excellent	Low/Med	Low	Low	Good	Good	High
RECHARGEABLE	Yes	Yes	Yes	No	No	No	No
LIGHT WEIGHT	Yes	No	No	No	No	Yes	Yes
SAFE	Yes	Good	Good	Low	Good	Good	Good*
GOOD PERFORMANCE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
COST	Low	Med	Med	High	Med	Med	High

*Depends upon particular system

FIGURE 3

batteries, there is a rechargeable version. Figure 2 is an overview of several energy density chemistries. As you can see, Alkaline Manganese is an improvement over the zinc carbon and nickel-cadmium, but has only 40% of the energy density of mercury.

Alkaline batteries are available in sizes from 40 MAH button cells to multiampere hours "D" cells and battery voltages from 1½ volts to 9 volts.

Advantages of the alkaline battery are its high rate efficiency, improved shelf life of 3-5 years, good to excellent low temperature performance, cell voltage of 1.55 to 1.6 volts, and low cost.

Disadvantages are its low to moderate energy density. Alkaline button cell batteries have insufficient energy to meet memory backup power requirements for several years of operation. Elevated temperatures accelerate the self-discharge rate, limiting its overall service life.

Figure 3 compares the alkaline manganese battery to the ideal power cell.

Present day applications for this battery are LCD calculators, cameras (exposure control system and strobes), and toys.

Silver Oxide

Silver oxide batteries were commercially developed about 10-15 years ago. There are two similar chemistries used in commerical silver oxide button cell batteries, monovalent and divalent silver oxide.

Figure 2 lists the energy density of both silver oxide chemistries. Monovalent silver oxide has the formula Ag_2O and falls between alkaline and mercury. Divalent has the formula AgO and offers the highest energy density outside of the Zinc-Air system. (The mechanics of activating/deactivating a Zinc-Air battery prevents its use in battery backup applications.) The high energy densities lend themselves to miniature button cells. Almost all commercially available silver oxide batteries are button cells. The development of larger cylindrical size silver oxide batteries is possible but is restricted by the price of silver.

Characteristics of the monovalent and divalent cells are their high energy densities - about 2 - 2½ times that of alkaline, an operating voltage of 1.55 volts, light weight, good low and high rate current capacities, a shelf life at room temperature of 3 to 5 years in high rate cells, and 4 to 6 years in low rate cells, good low temperature operation, and low leakage rates.

Disadvantages of both types are the increased self-discharge rates which occur when cells are subjected to high temperatures for extended periods of time. The fluctuating market price for silver in the past couple of years has increased silver oxide button cell prices significantly. Currently, silver is below $10/Troy Oz. and it is again a viable cost product.

Differences between mono and divalent cells occur in two areas. First, divalent has a higher energy density, about 30% more, than monovalent. In the same size cell, divalent can offer significantly more energy. Second, divalent chemistry produces a higher cell voltage of 1.8 volts compared to 1.55 volts for monovalent. In commercial divalent silver oxide cells, special techniques are used to reduce the voltage to 1.55 volts without sacrificing the higher energy density.

In terms of low temperature operation, a divalent silver oxide watch cell measuring 11.56 mm diameter by 5.36 mm high and rated at 1.5V, 220 MAH, has delivered 113 microamperes at -70°F at a closed circuit voltage of 1.44 volts.

Silver oxide button cell batteries range in size from 2.10 mm high by 6.80 mm diameter to 5.36 mm high by 11.56 mm diameter and capacities of 17 MAH to 220 MAH.

Figure 3 compares both silver oxide battery systems to the ideal power cell.

Lithium Batteries

The most exciting new battery system entering the marketplace today is lithium. Actually, it should be referred to as lithium systems since there are in excess of 10 different systems that use lithium.

Figure 4 is a partial listing of companies and the lithium technologies they are or have investigated.

The primary incentive for the development of lithium batteries is their potential for very high energy densities which in small batteries can realistically be expected to be 450 to 760 Watt-Hours/Liter delivered. Another incentive is the higher cell voltage of 2.6 to 3.6 volts. Lithium batteries also exhibit shelf lives of 5 to 20 years depending upon the particular lithium system. They can also operate at low temperatures to which conventional batteries would be inoperative.

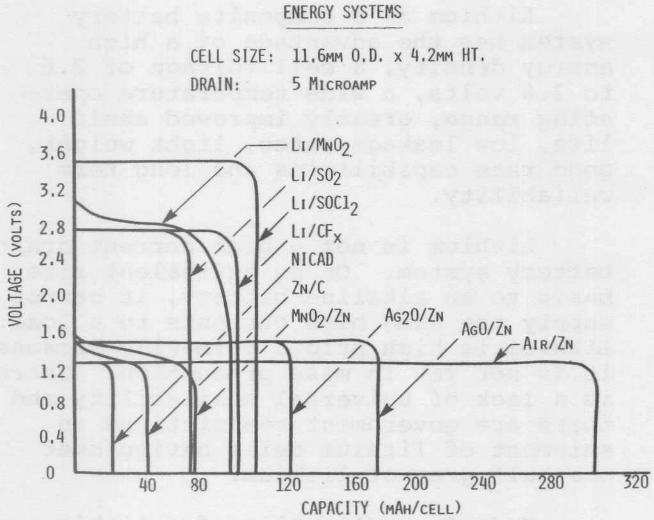
PARTIAL LISTING OF COMPANIES INVOLVED IN LITHIUM CELL DEVELOPMENT/MANUFACTURE

COMPANY	LITHIUM SYSTEMS
RAYOVAC CORP.	MnO_2, CuS, Cu_2S, $SOCl_2$, Ag_2CrO_4, FeS, CF_x, SOLID STATE
TOSHIBA RAYOVAC	MnO_2
SANYO	MnO_2
MATSUSHITA	CF_x, CuO, MnO_2
UNION CARBIDE	MnO_2, FeS_2, $SOCl_2$
MALLORY	MnO_2, SO_2
HITACHI-MAXELL	FeS
GENERAL ELECTRIC	MnO_2
HONEYWELL	$SOCl_2$, V_2O_5
GTE	$SOCl_2$
EAGLE-PITCHER	CF_x
VARTA	MnO_2, Bi_2O_3
BEREC	MnO_2
ALTUS	$SOCl_2$
ULTRA ENERGY	SO_2
CATALYST RESEARCH	SOLID STATE
WILSON GREATBACH	Br_2 COMPLEX, SOLID STATE, Ag COMPLEX
SAFT	CuO, $Bi_2Pb_2O_5$, MnO_2, $SOCl_2$, Ag_2CrO_4
PCI	SO_2
TADIRAN	$SOCl_2$

FIGURE 4

Lithium is the lightest metallic element known to man and is very reactive. It is a far more reactive material than zinc and even surpasses potassium and sodium. The extreme reactivity of lithium metal, which theoretically makes it such an attractive anode material, also makes it very difficult to work with. In the presence of water vapor or water it can ignite spontaneously. Hence, assembly must take place in dry rooms and the seals on the cells must be of a very high quality.

In terms of lithium chemistries which are at a production or prototype level, the major ones are solid state, sulfur dioxide (SO_2), carbon monofluoride (CF_x), manganese dioxide (MnO_2), and thionyl chloride ($SOCl_2$). Figure 2 compares the energy densities for these lithium systems. Figure 5 is a graph of their discharge characteristics.



CHARACTERISTIC DISCHARGE VOLTAGE OF ENERGY SYSTEMS
FIGURE 5

Solid State

Lithium solid state batteries are as their name implies, composed of a solid anode, solid electrolyte, and solid cathode. Combined with hermetic sealing, they may achieve shelf lives of 10 to 20 years or longer.

Solid state batteries were initially used in cardiac pacemakers where high reliability, low drains, and long operational life were extremely important. As power requirements for CMOS memories were reduced to the low microampere range, a new application for solid state batteries developed.

Solid state batteries offer a high energy density, approximately twice that of the alkaline battery, a long shelf life of 10 to 20 years, a wide temperature operating range of -55°C to +125°C, no leakage, a cell voltage of 2.8 volts, and a flat discharge characteristic.

In button cell sizes the principal limitation is a typical current drain of 20-25 microamperes, 50 microamperes maximum. They also have a moderate to high cost.

As the standby power requirements for CMOS RAMs continue to fall into the low and sub-microampere range, more applications will develop for solid state lithium batteries.

Lithium/Manganese Dioxide

Lithium manganese dioxide cells consist of a lithium anode, separator, manganese dioxide cathode, and an organic electrolyte. They have a nominal cell voltage of 3 volts and deliver approximately 2.9 volts under load. Its energy density is better than twice that of an alkaline battery. They usually employ crimp seals but can use a hermetic seal if the application so requires. The shelf life is estimated at 5 to 10 years. Lithium manganese dioxide cells are available in button cell and cylindrical sizes ranging in capacity from 30 MAH to 1000 MAH.

Advantages are its high energy density, 3 volt cell voltage, good rate capability, low self-discharge rate, has a temperature operating range of -20°C to +50°C, and a sloping discharge which lends itself to end of battery life sensors.

Lithium/Carbon Monofluoride

Lithium carbon monofluoride cells consist of a lithium anode, separator, carbon monofluoride cathode, and an organic electrolyte. The nominal cell voltage is 3 volts and 2.8 volts under load. It has an energy density slightly higher than that of lithium manganese dioxide. Lithium carbon monofluoride cells are available in sizes from button cells to "C" size cylindrical cells. Crimp seals are used in both the button and cylindrical cells. Shelf life is estimated at 5 to 10 years. Capacities range from 40 MAH to 5 AH. The button cells can deliver continuous currents up to 250 uA with pulsing up to 10 milliamperes. The larger cylindrical cells can deliver currents from microamperes to hundreds of milliamperes.

Advantages are its high energy density, cell voltage of 3 volts, good rate capability, low self-discharge rate, and an operating temperature range of -20° to +60°C.

Lithium Thionyl Chloride

Lithium thionyl chloride cells are a high voltage, high energy density lithium system. Figure 2 shows lithium thionyl chloride at the top of the list.

If lithium systems were classified as low, medium, or high rate, thionyl chloride would fall in the high rate category. It has a nominal voltage of 3.6 volts and is commercially available in sizes from .85 AH to 10.8 AH.

They are available both in low profile prismatic and conventional cylindrical shapes. The basic construction consists of a lithium anode, a separator, a carbon cathode, and a thionyl chloride electrolyte/depolarizer.

Advantages are: a very high energy density, a high cell voltage, excellent rate capability, with hermetic seals - a shelf life of up to 10 years, a very low self-discharge rate, and a temperature operating range of -55°C to +70°C.

Disadvantages of the system are its susceptibility to a voltage delay problem. If initially unused for some period of time, a passive layer develops on the anode. If the cell is subjected to a light current drain, the voltage drop will be very small to non-existant. It is only on a heavy drain that the cell voltage drop is pronounced. The delay time during heavy drains can be several seconds in length. Under both light and heavy drains the layer is dissipated.

Lithium Sulfur Dioxide

Lithium sulfur dioxide cells have been in production for several years, primarily for military markets. They are available in sizes of .43 AH up to 30 AH. The nominal cell voltage is 3 volts and 2.8 volts under load. The basic cell is spiral wound consisting of a lithium anode, a separator, a carbon cathode, and a sulfur dioxide rich electrolyte. The cells are usually hermetically sealed. The sulfur dioxide cells are operated at a positive internal pressure which can reach 100-200 PSI (pounds per square inch) at elevated temperatures. The operating temperature range is -65°F to +165°F. At temperatures between 230°F to 250°F and pressures of 450 to 500 PSI, a safety vent is activated rendering the cell inoperative. The sulfur dioxide system can sustain currents from microamperes to amperes in its "D" cell size. Shelf life is estimated to be about 10 years.

Lithium sulfur dioxide cells are also susceptible to the same type voltage delay seen with lithium thionyl chloride. Here too, good progress is being made to eliminate the problem.

Lithium as a composite battery system has the advantage of a high energy density, a cell voltage of 2.6 to 3.6 volts, a wide temperature operating range, greatly improved shelf life, low leakage rates, light weight, good rate capabilities and long term reliability.

Lithium is not a high current drain battery system. On an equivalent size basis to an alkaline battery, it cannot supply the same high currents to a load. Lithium is high priced primarily because it is not yet in mass production. There is a lack of universal availability and there are government restrictions on shipment of lithium cells having over one-half gram of lithium.

Today's applications for lithium button cells are strongest in the watch and calculator markets. However, a growing number of applications for button cells as small as the 40 MAH to as large as multiampere hour thionyl chloride cells, are appearing in industrial controls, test equipment, telephones, memory backup, and computer clock/timing functions.

Figure 3 compares the lithium systems with the ideal power cell.

CONCLUSION

The microelectronic system designer now has a broad portfolio of battery systems with which to meet his backup power requirements. Secondary batteries like the Nickel-Cadmium and Sealed Lead Acid should be considered where the application could require frequent replacement of primary batteries, where high current drains are required, where primary batteries may not be replaced, and if rechargeability makes the device more desirable to the user. Primary batteries like the silver oxide and lithium systems can offer many years of reliable protection for volatile memories and clocks, can reduce maintenance, and in some cases may be good for the life of the equipment, can eliminate the need of charging circuitry, can operate over broad temperature ranges, and can be directly mounted on the printed circuit board.

While this paper presents some design guidelines for selecting and applying primary and secondary batteries, it is by no means complete. It is intended as a guide to you, the systems designer, for determining your battery requirements.

In the process of making your battery selection, it is very important to solicit more detailed information and assistance from the battery manufacturers. Generally, manufacturers have a group of trained application engineers to provide technical assistance and specification guidelines. By working with the battery manufacturer, you can minimize risk in product design, optimize product performance and continue the successful alliance of batteries with microelectronics.

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ULTRA-LOW POWER CMOS MEMORY FOR BATTERY BACK-UP APPLICATION

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It was becoming widely acknowledged that the Complimentary-Metal Oxide-Silicon (C-MOS) process provides many advantages over other processes in fabricating modern integrated circuits such as Random-Access-Memories (RAMS) and logic circuits. The major advantages of the C-MOS process over other MOS processes are 1) wider operating temperature range; 2) wider operating voltage range; 3) higher noise margins; and 4) low power consumption. Until recently, the major disadvantage to the C-MOS process has been slow operating speed but, as we shall show in this paper, this disadvantage has been overcome by advancement in both circuit design and process capability by Toshiba Corporation which has culminated in the very popular TC5516/17/18 series of 16K static C-MOS RAMs currently in production.

The ability to produce a high-density RAM with fast access time (200 nSec) and exceptionally low power consumption (2-3 nA) during stand-by operations has opened many new application opportunities where non-volatile memory retention or low operating power are key issues. This article will describe this new family of ultra low standby power CMOS RAMs and their use in non-volatile battery backup applications.

CMOS RAM

The characteristics which make CMOS RAMs ideal devices for non-volatile memory storage applications are their very low power dissipation and their very low voltage requirement (2V) during standby operation where the only function of the device is to retain the memory information already stored in the device.

Figure 1 through 3 are presented to describe how these merits are achieved in CMOS RAMs.

Figure 1 describes a typical CMOS memory cell structure. This basic circuit is used to store one bit of digital information and is replicated many times within the completed RAM device. This circuit is known as a "bi-stable flip-flop". The bi-stable flip-flop has only 2 stable operating modes: either Tr1 and Tr4 are both on (resulting in the storage of a "0" logic level), or Tr2 and Tr3 are both on (resulting in the storage of a "1" logic level) in the cell. Either of these two stable conditions will be maintained as long as VDD is larger than the sum of the voltages necessary to turn on one P-channel transistor (Tr1 or Tr2) and one N-channel transistor (Tr3 or Tr4). These two voltages are essentially the threshold voltages of the transistors and usually are in the range of 1-2.0 volts and it is this characteristic that gives CMOS RAM the ability to maintain stored data with VDD down to the 2V level.

Further investigation of this circuit indicates that when the bi-stable flip-flop is in either of its two stable states, no DC path exists between VDD and VSS because one pair of transistors is always off. This characteristic results in the very low standby current consumption of the CMOS RAM during inactive periods of operation.

Figures 2 and 3 describe this structure in more detail. Figure 2 shows a cross section of the CMOS inverters used to implement a memory cell. Figure 3 is a schematic representation of the inverter. When this inverter circuit is in either of the two stable conditions, it can be seen that the P-channel transistor and the N-channel transistor cannot be turned on simultaneously. This means that essentially no power is dissipated in the inverter when the circuit is in a stable state.

In reality, however, a very small amount of power is dissipated even in the stable states because the transistors are not "ideal" and therefore a small leakage occurs even in the off condition. The magnitude of the leakage current is proportional to the area of the p-n junction used to form the transistor, and, in the case of the TC5516/17/18, the dominant component arises from the junction formed by the Pwell and the N substrate (the Pwell-Nsub junction). In a normal CMOS RAM, the total area of the Pwell-Nsub junction is very close to the total chip area. Using 5mm X 5mm as an approximate chip size and 0.1 NA/mm2 as a typical leakage current density at room temperature, the expected CMOS RAM leakage current in standby mode is 2.5 nA.

The leakage current is dominated by the "Carrier Generation/Recombination" effect and therefore is temperature sensitive. The expected change in G-R related leakage with temperature predicts that this leakage current will double with every 10 C increase in temperature. Thus, if 1nA of leakage is observed at 25 C, the expected leakage of the same device at 85 C would be 64nA.

Low Standby Power CMOS RAM

As was described above, the standby power dissipated in a CMOS RAM is determined by the leakage current across the reverse-biased P-N junction in the device. In the actual device, the dominant causes of Generation-Recombination Centers in the device are metallica impurities found in the depletion layer of the P-N junction. These metallic impurities in the depletion layer act as additional Generation-Recombination Centers (beyond the normal expected due to crystal imperfections or intersticial sites) and therefore add significantly to the background leakage current.

Toshiba has developed proprietary CMOS process technology which enables the reduction of these metallic impurities in the P-N junctions by a significant amount. Toshiba utilizes this process in the production of the currently available TC5516 APL device, a 16K Static CMOS RAM. Typical standby current values at room temperature for this device are 2-3 nA. Figures 4 and 5 describe the leakage current characteristics of the TC5516 APL versus voltage and temperature. Figure 6 is the standby current distribution data for a typical diffusion lot. Approximately 90% of the distribution have standby current less than 10 nA and the center of the distribution is 2-3 nA.

The above standby characteristics make the TC5516/17/18 APL devices very attractive and practical for non-volatile memory storage applications where a primary battery such as a Lithium Cell (rather than a rechargeable cell like Ni-Cd) is the main power source.

Table 1 lists the current products from Toshiba which exhibit these very low standby power characteristics.

Battery Back-up Applications

Since these devices exhibit such exceptional standby characteristics, their major applications are in battery backup systems. Toshiba has incorporated several "easy-to-use" features in the fundamental design of the parts with these applications in mind.

The first is compatiblity with existing N channel MOS RAMs which have been widely used for years. The RC5504 APL (4K X 1) and TC5514 APL (1K X 4) 4K CMOS RAMs are pin-compatible and functionally equivalent to the MK4104 (4K X 1) and i2114 (1K X 4) NMOS RAMs respectively. The memory speed, which in the past has been one major drawback in the use of CMOS memory, has been dramatically improved in recent years and the timing of the TC5504 APL and TC5514 APL are essentially equivalent to the corresponding NMOS RAM. This, then, makes it very convenient for users to change existing designs from 4K NMOS RAMs to non-volatile 4K CMOS RAMs without changing the memory board itself.

"Easy-to-use" features in battery backup applications was given full consideration in the design of the recently developed and marketed 16K CMOS RAMs.

The 16K CMOS RAMs are available in the industry standard 24 pin, 600 mil dual-in-line package and with a pin-out compatible with the very

popular 2716 16K EPROM. Additionally, to provide even greated flexibility for assembly on the memory board, two different pin-outs were developed.

The TC5517 APL/BPL was developed to achieve pin-out compatibility with NMOS 16K RAMs such as the popular TMM2016P. The TC5516 APL and TC5518 BPL were developed specifically for battery backup applications where one of the two available chip-enable signals can be used to control the data retention mode for the entire memory board. For these devices, CE2 is the signal used to place the device into the standby mode. This signal can be commonly connected to all devices on the board and when simply pulled to a high logic level, used to place all memories on the board in the standby, power-down, data retention mode.

Another merit of the TC5516/18 devices in battery backup applications is that the input voltage level required for all inputs to the memory during standby operation need only to be TTL compatible signals. This is due to the internal design of the device which gates all of these inputs with the CE2 signal in a NOR configuration. This fully eliminates the need for external pull-up resistors which are normally required for other types of CMOS RAM with only one chip-enable signal.

Replacement of EAROM and EEPROM with Lithium Battery Backup TC5516 APL

As was shown in Figure 6, the TC5516 APL has extremely low standby current. Figure 7 is an estimated data retention lifetime of a typical TC5516 APL memory system using a long life Lithium battery for backup. The worst case standby current in the TC5516 APL was assumed from Figure 6 to be 50 nA, which is 5 times the average standby current in the device. A fully populated 64K byte system, which would use 32 of the above devices, exhibits a data retention time of greater than one year. An 8K byte memory system, using 4 of the above devices, would have an expected data retention time of greater than 10 years for just a single small button type Lithium cell. This is comparable to the predicted data retention time of both EAROM and EEPROM. Additionally, when you compare other characteristics such as write cycle time, you find that the CMOS RAM implementation is superior by several orders of magnitude.

A third alternative over EEPROM and EAROM is that both of these devices experience a "wear-out" phenomenon each time information is written into the memory. The current predictions show a maximum number of writer cycles for each of these devices on the order of 10^5 cycles. In any common computer or microprocess application, 100,000 write cycles can be accumulated very early in the installed life of the equipment making these non-volatile types of memories unusable for a majority of applications. CMOS RAM does not experience this wear-out phenomenon and therefore can be written to an unlimited number of times without wearing out. A major and distinct advantage of CMOS RAM over EAROM and EEPROM.

Basic Circuit for Battery Backup CMOS Application

Figure 8 shows the basic circuit used to provide backup power from a battery to a CMOS RAM. When the system power supply is at its normal operating voltage, diode D1 is conducting (passing current) and diode D2 is non-conducting, which isolates the CMOS RAM from the battery. In this condition, the actual voltage provided to the CMOS RAM is VS (power supply voltage) - VF1 (forward voltage drop of diode D1). When the power supply fails and VS begins to fall, diode D2 will begin to conduct when VS-VF1 < VB-VF2 is established. The resulting voltage to the CMOS RAM will then be VB (battery voltage) - VF2. Since this value can drop all the way to 2V using the TC5516 APL, data retention will be guaranteed for battery voltages down to approximately 2.7V.

This circuit is the simplest possible backup mode and operates in a fully passive mode.

Battery Backup Memory Circuit Using 16K CMOS RAMs with Two Chip-Enables

For this example circuit, Figure 9, when the system power is at its normal operating voltage, diode D1 and transistors TR1 and TR2 are all on (on conducting), and the resulting

VDD to the CMOS RAM is VS-VSAT2. VSAT2 is the saturation voltage of transistor TR2 and is typically 0.2V for common transistors. Referring to the previous example, Figure 8, the forward voltage drop of diode Dl, VFl, is typically in the range of 0.6 - 0.8V, which is considerably higher than VSAT2. Thus it can be seen that the circuit shown in Figure 9 will deliver actual voltage to the CMOS RAM much closer to VS than in Figure 8. This difference is occasionally important to ensure the entire system works within the guaranteed voltage range. Guaranteed operational voltage range for systems using TTL or LSTTL gates if 5V+5% which CMOS RAMs usually allows 5V+10%. Using a circuit similar to Figure 9 with VSAT2 0.2V, 5V+5% - VSAT still satisfies the RAM requirement of 5V+10%.

When the system power supply fails and the voltage starts to drop, the voltage from the backup battery is fed through diode D2 as soon as Dl, TRl and TR2 turn off and the relationship VS < VBZ + VBEl is established. The voltage level at the memory during backup operation will be VDD=VB-VFZ. However, it is necessary, before VS < VBZ + VBEl is fully established, to make the Data Retention Control Signal, CDRC, a logical high and therefore place the memory system in the data retention mode. Figure 10 shows the data retention voltage characteristics of the TC5516 APL.

It should be noted here that a low-power shottly gate (LSTTL) should not be used for the Data Retention Control Gate. In LSTTL circuits, the output terminals are connected to the power supply rail through an internal resistor which when used as the Data Retention Control Gate, will sink the battery current and degrade the life of the backup battery. Standard TTL gates and CMOS logic gates which have no such internal current path should be used.

In Figure 9, the benefits of two chip-enables found in TC5516 APL and TC5518 APL have been fully utilized with CE2 commonly connected to all memory devices on the board through a single control line.

The following are additional advantages users can expect with TC5516 APL and TC5518 BPL in battery applications.

TC5516AP/APL

High speed memory systems can be implemented by using the fast access from chip-enable feature. Access time from CEl for the TC5516AP/APL is 100 nsec max.

TC5518BP/BPL

Both CEl and CE2 can be used to control the power down mode so that for large arrays, an X-Y decode arrangement can be used to control the active selection. This results in only one device being active at any time and therefore the average power consumption of the system is reduced dramatically.

Large Capacity Memory Application

This example, Figure 11, shows the use of the two chip-enables of the TC5518BPL to make two-dimensional memory capacity expansion very simple.

The configuration of the battery backup circuits and its operating principles are identical to those discussed earlier in Figure 9. The TC5518BPL is most suited for this type of system because the two chip-enable pins have identical functions and can be used interchangeable. Futhermore, the number of decoded circuits necessary to decode the multichip memory system is minimized in this 2 dimensional memory array where 2n decoders can decode n2 memory chips.

In an actual application where the memory system is used with a CPU whose data must be transferred and stored in memory when the power fails, it is necessary to detect the power failure as early as possible so that the DC voltage in the system is still sufficiently high to ensure accuracy during the memory write operations while VDD is falling. By utilizing power down voltage detection circuit which detects off the AC power supply line as is shown in Figure 12. The earliest warning of a power failure can be generated. This signal can be detected by the CPU resulting in the storage of critical data which VDD is still at its maximum, and then

to generate the Data Retention Control signal which puts the memory system into the standby mode with battery backup.

When the memory system is used only as a ROM replacement and no writing to the memory occurs, the power fail signal, when detected, would simply place the system into the backup mode.

SUMMARY

The capacity of high-technology semiconductor memories, supported by improvements in finer, more advances, process technologies, has quadrupled every 2 years essentially without increasing the chip size of the devices. This indicated that the standby current of CMOS RAM will remain essentially constant even though the storage capacity of the devices will continue to increase. This fact and the basic benefit of low power dissipation of CMOS make the CMOS RAM increasingly more attractive for future applications, where low power and non-volatility are key issues.

The low power performance of CMOS RAMs in the standby mode has improved to such a stage where even a small button type Lithium battery can be used to maintain data as long as 10 years.

New devices from Toshiba, TC5564 and TC5564, 64K Static CMOS RAMs, which are soon to be released should contribute heavily toward this direction in the future.

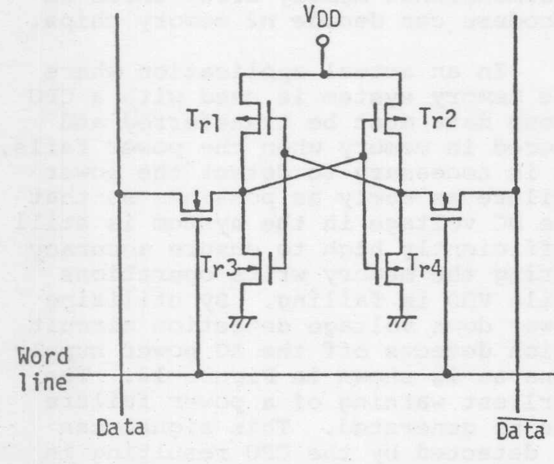

Figure 1. Circuit Diagram of CMOS Memory Cell

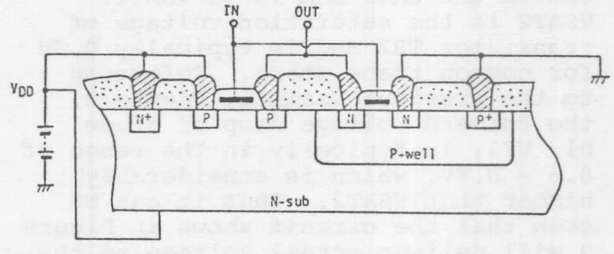

Figure 2. Cross Section of CMOS Inverter

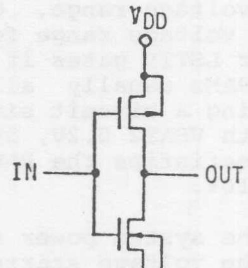

Figure 3. Circuit Diagram of CMOS Inverter

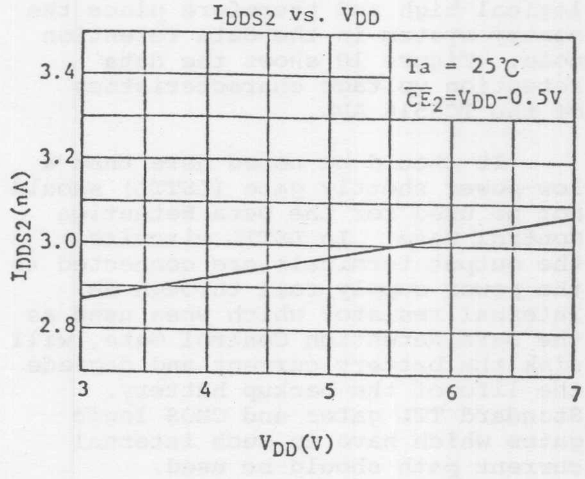

Figure 4. Standby Current vs. VDD

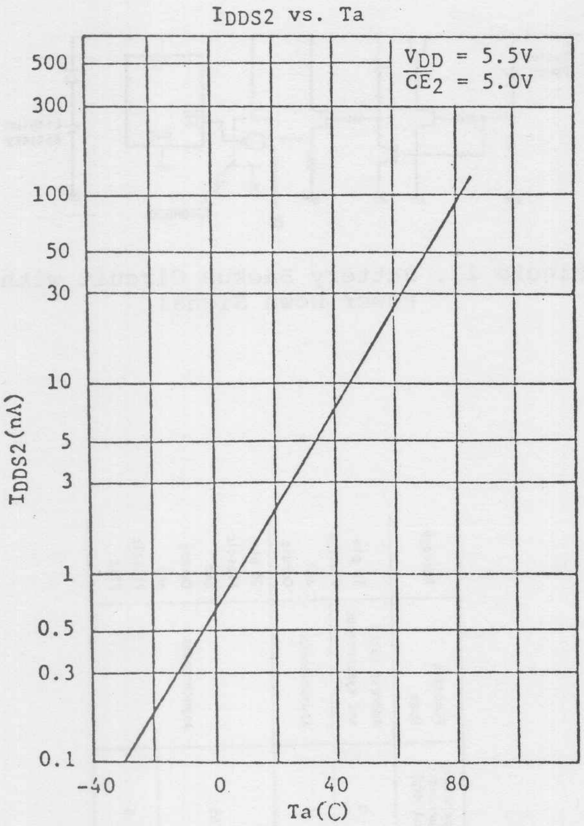

Figure 5. Standby Current vs. Ta

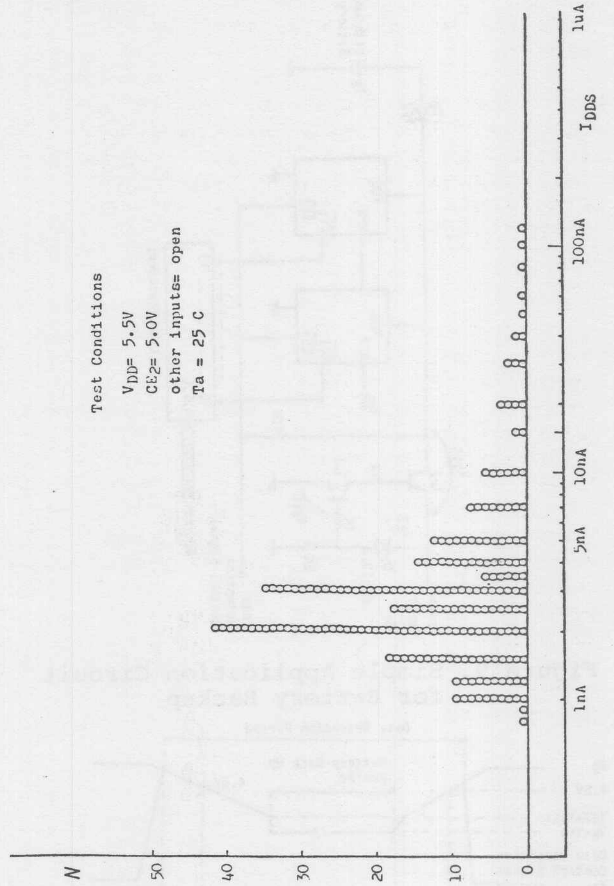

Figure 6. TC5516 APL Standby Current (IDDS2) Distribution Data

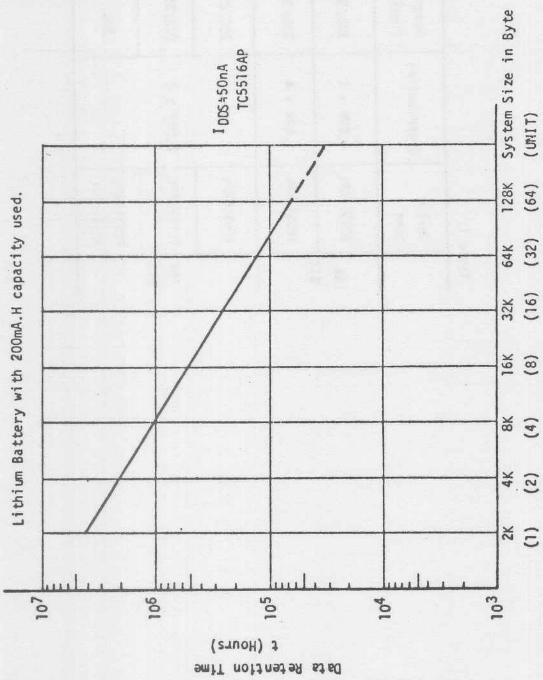

Figure 7. Data Retention Time vs. System Size

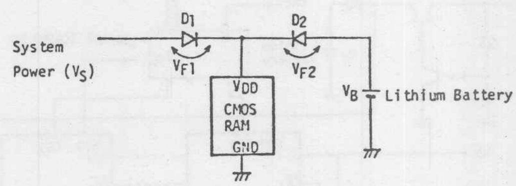

Figure 8. Basic Circuit for Battery Backup Application

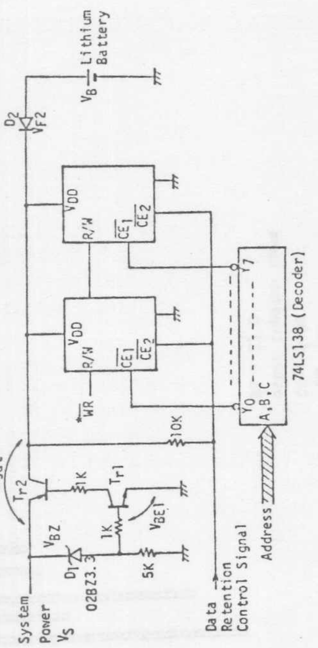

Figure 9. Simple Application Circuit for Battery Backup

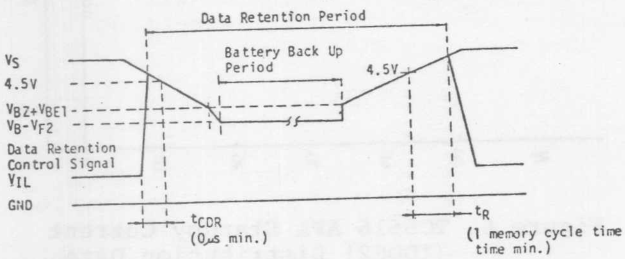

Figure 10.

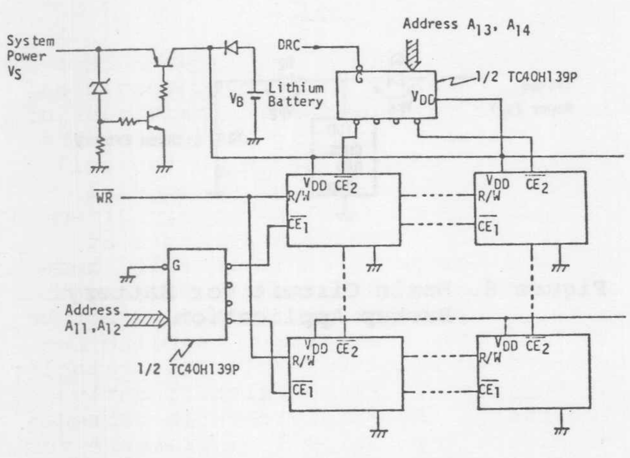

Figure 11. Large Capacity Memory Application

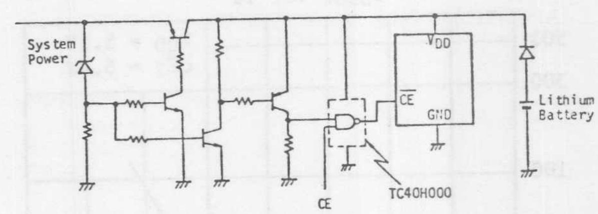

Figure 12. Battery Backup Circuit with Power Down Signal

Table 1.

	Device Name	Organization	Access Time(ns)	Operating Current (mA/MHz)	Function Mode	Package
4K Bit	TC5504APL	4,096 x 1	200/300	5	Address latch and synchronous	18 pin Plastic and Cerdip
	TC5514APL	1,024 x 4	200/300	5	asynchronous	
16K Bit	TC5516APL	2,043 x 8	200/250	55	asynchronous	24 pin Plastic and Cerdip and Plastic Flat
	TC5517APL		200/250			
	TC5517BPL TC5518BPL		200	5		

APPLICATIONS OF LITHIUM IODINE BATTERIES TO CMOS MEMORY AND MICROPROCESSORS

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INTRODUCTION

Applications of batteries for continuous long-term memory backup are not as easy or as simple as one might first assume. It requires consideration of not only the battery but also the type of switch to be used to turn the battery on and off, and the interface between the memory (or microprocessor) and those components not under battery power.

We have chosen a long-life, solid-state, lithium-iodine battery which has been used in the cardiac pacemaker industry since 1972. Today, this battery powers more than 90% of the world's pacemakers, and its reliability is well documented.

We have also designed and tested the switching, control and interface electronics needed for reliable data retention under battery operation, and during the transistions to and from the normal (DC) power supply.

THE BATTERY

The battery is a solid-state, high energy density, long-life primary cell. It uses lithium metal as the anode, a solid pellet of iodine imbedded in an organic polymer as the cathode, and solid lithium iodide as the electrolyte and separator. It cannot suffer from separator rupture or loss of electrolyte, which are common failure mechanisms in most batteries, because the separator/electrolyte is solid and self-healing.

The open circuit cell voltage is 2.793 volts at 25 C and at end-of-life is only 3 millivolts less. The temperature coefficient of open circuit voltage is about +1 millivolt per degree Celsius. Most CMOS memories will retain data at 2.0 volts, leaving almost 0.8 volts for loss in the battery due to polarization, temperature change and voltage loss in external circuits.

The cell current available is limited by the internal impedance of the battery and the minimum operating voltage required by the device under battery power.

The cell impedance varies with capacity extracted and the cell temperature. For a given capacity extracted, cell impedance is essentially independent of the drain rate at which the cell had been used. Practically, this means the impedance is constant and predictable.

The available cell current, at a fixed voltage, increases with increasing temperature and decreases with decreasing temperature. The apparent cell impedance also varies with temperature, decreasing with increasing temperature.

Self-discharge is the electrochemical process in which battery energy is lost internally without doing any external work. The extent to which this process occurs in the lithium-iodine system is about 10% of capacity remaining over 10 years at 25 C. This is what makes the battery desirable for long-term use; most batteries will completely self-discharge in much less time.

Lithium-iodine cells can accept reverse currents both continuously and momentarily, provided the magnitude of the reverse current is kept below the limit that causes damage to the cell. A small reverse current of about 1 microampere will not adversely affect the battery. Preliminary tests at Catalyst Research indicate that these small reverse currents may prolong the life of the battery. It should not be assumed that the battery is being recharged by these currents; the capacity of the battery is not significantly increased. Momentary reverse currents should be kept below 1 milliampere for periods of 1 second since excessive reverse current can cause permanent cell

damage.

THE POWER SUPPLY SWITCHES

To readily interface the battery to a CMOS device requires the use of a switch to select battery or normal system power. The switch can be modelled as two single-pole single-throw switches with a common terminal. This configuration is necessary for make-before-break operation. The battery switch must operate under battery power, and need only pass small (<100 microamperes) currents. The other switch, for the normal supply, must pass sufficient current to operate the CMOS device in worst case situations without excessive loss of voltage. In addition, the normal supply switch must not present a load to the battery when the normal supply is off.

The Battery Switch

The battery switch can be a silicon diode, a germanium diode, or a field effect transistor (Fig. 1A,B). A relay may be used although its reliability over the life of the product must be taken into consideration.

The silicon diode is inexpensive and easy to use. The primary disadvantage of the silicon diode is the forward voltage drop. Although this drop may be as high as 0.7 volts at moderate currents, tests we have conducted show that a type 1N4148 diode at a forward current of 10 microamperes has a voltage drop of only 0.35 volts at 25 C.

The germanium diode is also an attractive switching device for the battery. Its forward voltage drop is much lower than that for a silicon diode. For a type 1N34A germanium signal diode at 10 microamperes forward current, the voltage drop is less than 100 microvolts at 25 C. However, because of the magnitude of the reverse bias current in germanium diodes, the battery may see significant reverse current under normal supply operation. Small reverse currents present no difficulty provided these currents do not exceed the capability of the battery.

The field-effect transistor has shown to be an almost ideal device for this application. In its on-state, the channel resistance is much less than the battery's internal impedance; in the off-state the channel resistance is almost infinite. Because the bias current for a FET is so small it uses no appreciable amount of the battery energy. There is some difficulty in using a FET since the gate-source bias voltage is at most the battery's open-circuit voltage, but by proper selection a suitable device may be found.

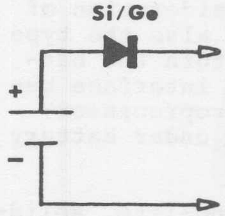

Fig. 1(A)

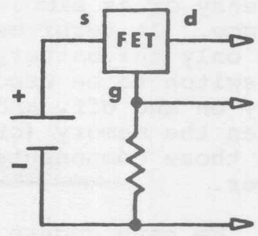

Fig. 1(B)

The Normal Supply Switch

The normal supply switch must pass sufficient current to operate the CMOS device without voltage loss great enough to cause logic level conflict. For CMOS devices this loss cannot exceed 0.3 volts, typically. The normal supply switch must also not load the battery when the CMOS device is under battery power. Two possible choices for the normal supply switch are a diode and a bipolar transistor (Fig. 2A,B).

The silicon diode is inexpensive and easy to use but its forward voltage drop in this application will be 0.7 volts because of the current required under normal operation. To prevent logic-level incompatibility, a separate supply voltage may be needed and a bias resistor to hold the diode drop at 0.7 volts at all times. The reverse bias current thru a low-leakage silicon diode is small enough that it will not load the battery during battery operation. A germanium diode would load the battery, and should not be used here.

The PNP-bipolar transistor is a very attractive switch in this application. A low emitter-collector saturation voltage and low reverse current thru the collector-base junction meets the requirements of the normal supply

switch. Suitable transistors are available for a wide range of normal supply currents. Caution must be exercised to avoid forward biasing the collector-base junction, and thereby loading the battery, during battery operation.

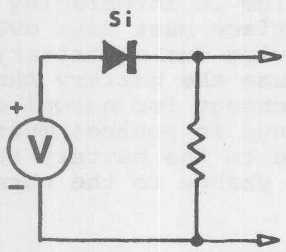

Fig. 2(A)

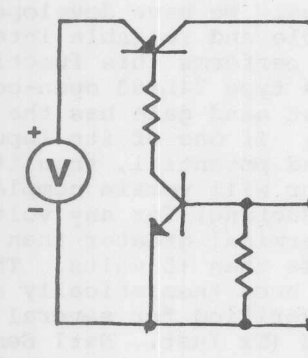

Fig. 2(B)

Transitions in Power Supplies

The steady-state operation of the switch, either in battery mode or in normal supply mode, is easily accomplished with combinations of solid-state devices as described. It is during the transition states, from battery to normal and normal to battery, that difficulties arise.

It is obvious that even short duration losses of power to a CMOS device will cause errors in the data contained in the device. Practically, this means that during power-up, the normal switch must close before the battery switch opens; and during power-down the battery switch must close before the normal switch opens. If a common signal is used to activate the changeover in power supply, the response of the switches must be guaranteed to meet this condition.

Lithium-iodine cells can accept reverse currents both continuously and momentarily, provided the magnitude of the reverse current is kept below the limit that causes damage to the cell. A continuous small reverse current of about 1 microampere will not adversely affect the battery. Preliminary tests at Catalyst Research indicate that these small reverse currents may prolong the life of the battery. It should not be assumed that the battery is being recharged by these currents; the capacity of the battery is not significantly increased. Momentary reverse currents should be kept below 1 milliampere for periods of 1 second or permanent cell damage can occur.

THE CONTROL MECHANISM

The control mechanism must determine power supply status and generate signals to switch between normal supply and battery supply. To facilitate the use of simple interfaces, the change from normal supply to battery supply should occur at about the nominal cell voltage; switching at this voltage implies logic-level compatibility during changes in power supply. A signal to indicate the mode of control of the memory (or microprocessor) must be generated to determine if access will be permitted by the system hardware; under battery power the memory (or microprocessor) must not be accessed because of excessive demand on the battery.

Power-Up/Down Sequences

In a typical application, a normal operation sequence consists of: power-up, operation on normal supply, and power-down. It is essential that the data retention system be capable of handling the shortest length sequence; the length of this sequence is dependent on particular normal power supply. Abnormal power supply situations must also be kept in mind to assure data retention during these times.

The power-up sequence can be approximated by a smooth rise from zero volts to the normal supply voltage. When the normal supply rises to the nominal cell voltage, the change to the normal power supply should occur. When the normal supply rises to the minimum DC operating voltage for the system hardware, access to the control of the

memory (or microprocessor) may be permitted.

A power-down sequence can be approximated by a smooth drop from the normal supply voltage to zero volts. When the supply drops below the minimum DC operating voltage for the system hardware, access should be denied to the memory (or microprocessor). When the normal supply voltage falls to the battery nominal cell voltage, the change should be made to the battery from the normal supply.

This technique of two level voltage detection will protect the memory (or microprocessor) hardware from most types of power supply failure and normal on/off use. The use of hysteresis at the critical voltage detectors will further enhance the hardware protection, designing fast power supply switches, characteristics of which were described before, will enable the hardware to handle abnormal power supply fluctuations with reliable data retention.

False-Write and Read Protection

A matter of great concern in battery backup is the prevention of a "false-write". A false-write is any attempt: (1) To write into memory data of questionable validity, or (2) The premature termination of a normal write cycle. The first case of false-write can be effectively prevented by inhibiting operation of the external hardware whenever the normal power supply voltage is below minimum DC operating voltage, and granting access on a power-up sequence only after establishing normal system operation. The second type of false-write, premature termination, occurs during a power fail sequence. Premature termination is prevented by sensing the impending loss of power before minimum DC operating voltage is lost, and halting system operation before insufficient voltage is available to complete the write cycle.

The power required for a normal read of memory usually exceeds the capability of the battery. Pead access must be prevented during battery operation or loss of data may occur due to a momentary drop of battery voltage below the minimum data retention voltage.

DIGITAL INTERFACING

The digital interfaces to battery-backed memory (or microprocessors) can be divided into three classes: Control signals, address signals, and data signals. Control signals present the most difficult problem in interfacing because the interface must take over control of the device during battery operation. Because the battery cannot supply enough energy for normal operation, the change in control must precede the change to the battery supply, and follow the change to the normal supply.

Control Signals

Control signals asserted low (negative) must be pulled high during battery operation. We have developed and tested a simple and reliable interface circuit that performs this function (Fig. 3A). A type 74LS03 open-collector, dual-input nand gate has the following property: If one of its inputs is held at ground potential, then its output transistor will remain completely off (not conducting) for any voltage at the Vcc terminal greater than zero volts and less than +5 volts. This property has been theoretically and empirically verified for several major manufacturers (Tx Inst., Natl Semi, others). This property has not been checked for more sophisticated LS-TTL devices; it is the simplicity of the 74LS03 internal construction that gives it this property. Therefore, a pull-up resistor connected to the CMOS memory (or microprocessor) Vdd terminal will hold the CMOS input connected to the 74LS03 output at cmos Vdd during the rise and fall of the normal power supply voltage. The signal that is held at ground potential at the nand gate input we call "Access Grant", for obvious reasons. The remaining nand gate input is the system control input with inverted polarity; we call this "Access Request." It is much easier to generate an access grant signal held at ground than to attempt to disconnect the CMOS input from the system control output with a switch. There is no need to be concerned with the access request line; it can fall to ground in any manner provided its voltage does not exceed the voltage at the Vcc term-

inal of the 74LS03.

Control signals asserted high (positive) present a somewhat less difficult problem, since the CMOS input must be held at ground. Using any open-output (collector or drain) device such as gates, comparators, or more sophisticated function devices, and connecting the pull-up resistor to a switch that turns the pull-up into a pull-down (to ground) will hold the CMOS input at ground. (Fig. 3B) is an example of this technique using a 74LS 05 open-collector inverter. Designing the appropriate switch for the pull-up/down resistor is an easier task than attempting to disconnect the CMOS input from the system control input. (Note: Analog switches usually do not function correctly during their own power-up/down, and are unreliable interface devices.)

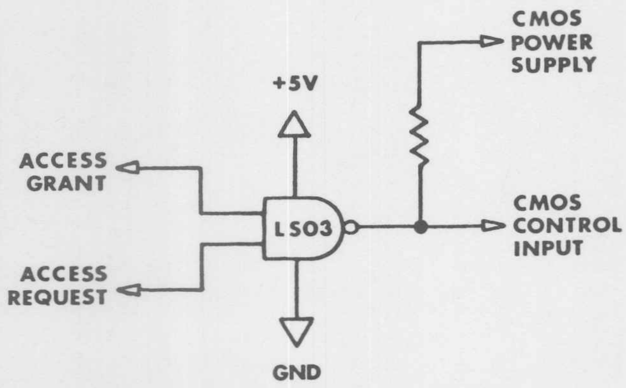

Fig. 3(A)

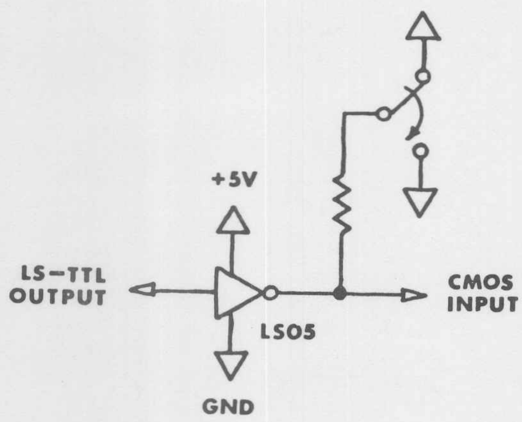

Fig. 3(B)

Address Signals

The problem of address signal interfacing is essentially one of avoiding voltages at the CMOS address inputs that fall in the CMOS input "Linear Region." This linear region is between the maximum input-low voltage and minimum input-high voltage. Input voltages in this interval cause both the N-channel and P-channel transistors to conduct heavily. This current is pulled through the power supply inputs; if the CMOS device is under battery power then the battery will attempt to source this current. Not only does this condition waste battery power, if it occurs simultaneously on many inputs it will saturate the battery and cause the cell voltage to drop below the minimum data retention voltage for the memory (or microprocessor), and the loss of data. This problem is solved by holding the address inputs at ground potential during battery operation. A careful choice of address bus-driver/interface will facilitate this. In any case, an interface like those for control signals described above will also work for address signals.

Data Signals

Data signals are the easiest to interface. If the data in/out to the memory (or microprocessor) is of the three-state bidirectional type then no interface is required if the data in/out terminals are in the high impedance state. The particular memory (or microprocessor) should be checked for excessive leakage current in the high-impedance state. Memory (or microprocessor) devices with separate data inputs and outputs can be treated like address inputs for data inputs; and data outputs should be disconnected from their loads, either internally or externally.

SUMMARY

The use of lithium-iodine batteries for long-term, uninterruptable power supplies for CMOS memory (or microprocessors) is quite feasible. Their applications in products can be separated into problems independent of each other, and the solutions of the problems can be integrated to form a highly reliable system without the use of expensive or difficult-to-find devices. We have developed a series of

successful products based on the lithium-iodine battery; in each case the probability of lost data was reduced to the probability of failure in the actual memory (or microprocessor) in the product.

Note:

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